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LABORATORY REPORT – EAR CONTROLLED DATA

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Report No.:	**B24060512**
Date Reported:	**06/28/2024**
P.O. No.:	**Pre-Paid**

Sample Description: Hail Damaged Roof Panels (5).

Forensic Investigation of Metal Roof Panels Reportedly Damaged in a Hail Storm

Introduction

Five segments from a metal roof that was reportedly damaged in a hail storm were submitted to Element Broken Arrow (EBA) by SJB Law Firm. These five damaged roof panels were reportedly sampled from Real Performance located at 1014-A North Nolan River Road, Cleburne, Texas 76033. Request for full replacement of the mechanically damaged roof in question was reportedly submitted via insurance claim; however, the insurance company asserts that mechanical damage to the metal roof is *only* cosmetic in nature. The insurance company's position therefore asserts that impact damage does not influence the expected/remaining service life and/or the functionality of the roof. The hail damaged metal roof segments submitted for the forensic protocol are displayed in Figure 1 in the as-received condition.

Conclusions

The forensic data in this report, both optically and via electron microscopy (EM), confirm that hail impact damage results in localized and accelerated corrosion of the base metal of each panel. The resulting corrosion products were due to the formation of iron oxides (*i.e.* rust). This occurred both in and around the center of impact point(s); and, in all areas that were analyzed the presence of elevated amounts of iron oxides was confirmed. The magnitude of the observed damage further resulted in migration of Fe from the base metal, through the protective coating system, and led to the formation of very heavy agglomerates of iron oxide(s). The former and latter were confirmed in multiple locations.

The forensic data in this report confirm that iron based corrosion products form specifically in the center of impact point(s); and that hail damage has resulted in the loss of corrosion protection. The forensic protocol therefore confirms that hail damage has influenced the functionality of the roof and that accelerated corrosion has influenced service life.

Report Approved by________________
Jeffrey Molnar
Failure Analyst

Note: The sample remains will be discarded 30 days after the date of this report, unless otherwise instructed.

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1.0. Optical Evaluation

The hail impact points on the submitted roof panels (Figure 1) each exhibited corrosion products in the approximate center of each damage location. These corrosion products were visually evident without the use of a microscope and they all exhibited optically reddish-brown appearance. The impact points were carefully extracted (Figure 2) for evaluation.

All of the hail impact points (Figure 3) exhibited relatively circular depressions with the center of each impact point deeper than the surrounding perimeter(s). Reddish brown corrosion products (Figure 4 yellow ellipses) were heavily concentrated at these impact points. Location 1B of roof panel No.1 (Figure 5) exhibited a very large depression and the entire depression exhibited evidence of elevated corrosion products. The impact point was so large that damage most likely occurred due to hail over 1" in diameter. The center of this point was so deep that impact perimeter(s) were heavily defocused (Figure 6). Localized corrosion products were characteristic of all impact points that were analyzed across multiple roof panel samples.

2.0. Electron Microscopy (EM)

2.0.1. Procedures

Segments of the metal roof prepared for analysis (Figures 2, 3, and 4) were examined directly without sputter coating or carbon coating the specimens. Testing was conducted using a Zeiss EVO10 LaB_6 scanning electron microscope (SEM) operating in high vacuum mode at a landing energy of 22.5keV. Elemental analysis was conducted using an Oxford X-Max energy dispersive spectroscopy (EDS) system.

Note: Direct analysis was successfully achieved without specimen charging with the EM tool operating in high vacuum mode; thus, variable pressure analyses were not necessary.

2.0.2. Results

In addition to localized corrosion within the center of hail impact points, the adjacent region(s) slightly offset from each point of impact were frequently micro-cracked due to bending (Figure 7a yellow arrows). The center of these impact points, which were precisely marked (green filled arrow) under the stereoscope (Figure 7b), exhibited evidence of heavily concentrated corrosion products. Closer inspection confirmed the presence of iron oxides that were frequently formed as agglomerates along micro-cracks in the Galvalume® protective layer (Figure 8). Moving towards the heaviest agglomerates confirmed that elevated iron oxides compared to the background (Figure 9) were also present, even in areas where top coat material remained. Moving to other points of hail damage (Figure 10) again confirmed that heavy agglomerates of corrosion products were present and the central as well as perimeter (Figure 11) regions exhibited iron oxides (*i.e.* rust). Finally, evaluation of many locations confirmed that aqueous phase formation and growth through the Galvalume® occurs with the result being formation of heavy concentrations of iron oxide (Figure 12). Based upon these analyses, there can be no question that both migration of Fe from the base metal through the protective panel coating(s), as well as the rapid oxidation of Fe to form rust, occurs specifically in the center of hail damage locations.

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Figure 1: Optical image of the damaged roof panels displayed in the as-received condition. Hail impact points are indicated (yellow paint pen).

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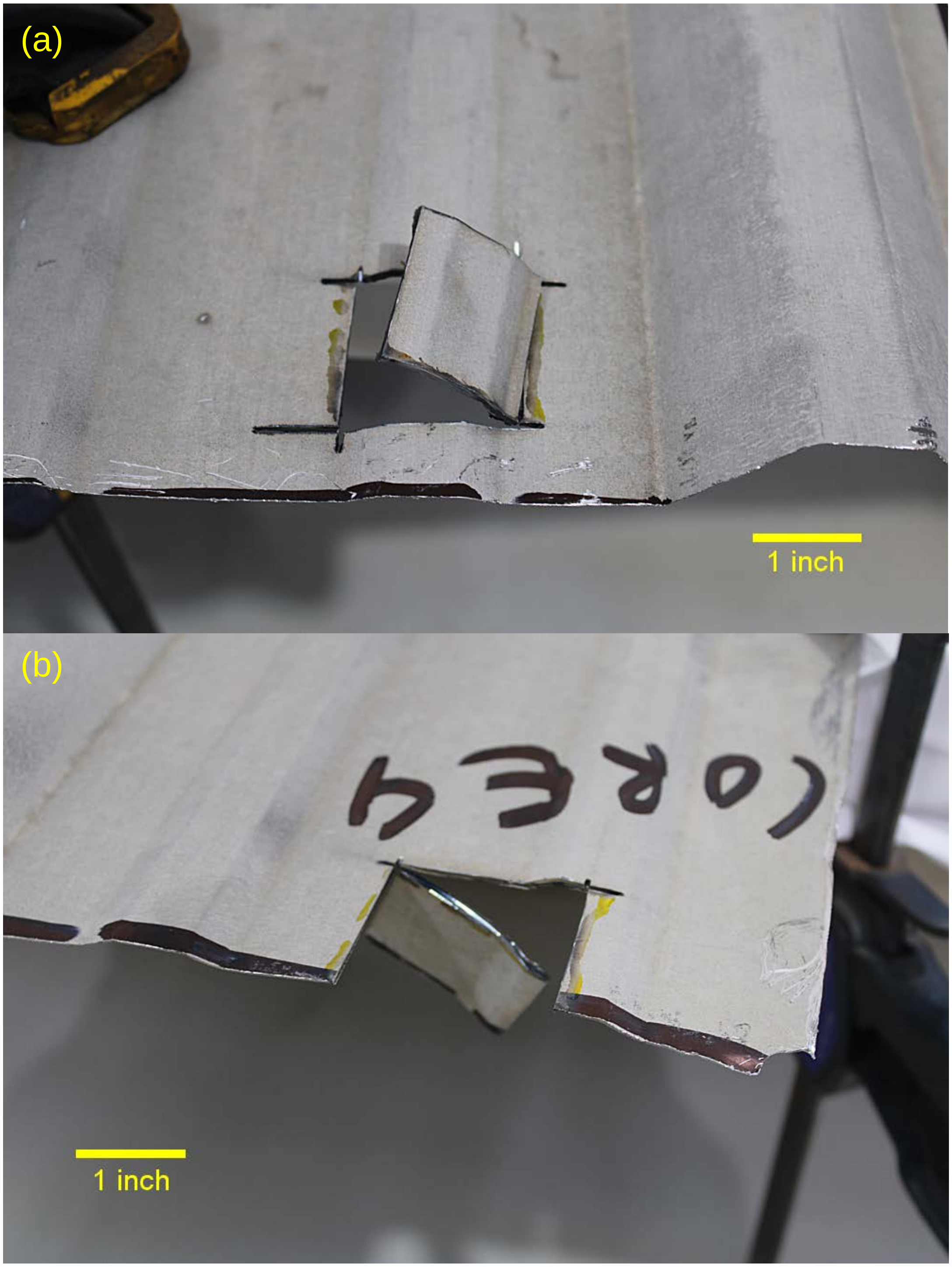

Figure 2: Optical images (a, b) showing the specimen extraction process employed to acquire specimens specifically at hail impact points. This process eliminates specimen preparation artifact as neither surface exhibiting damage is touched during extraction.

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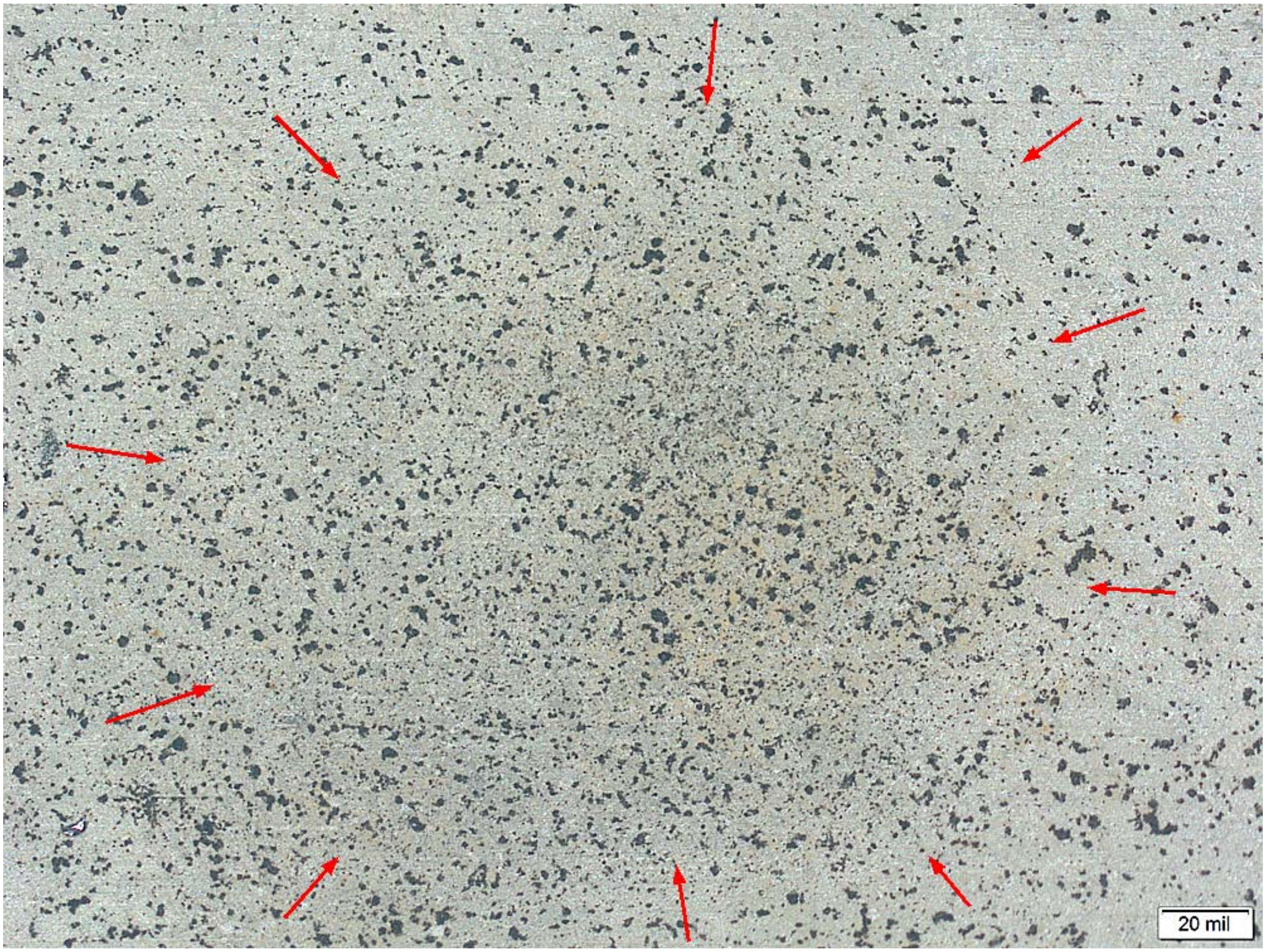

Figure 3: Stereo optical microscope image representative of the impact point of damage on roof panel No.1 impact point 1A (Figure 1). The scale bar is in mils (0.001").

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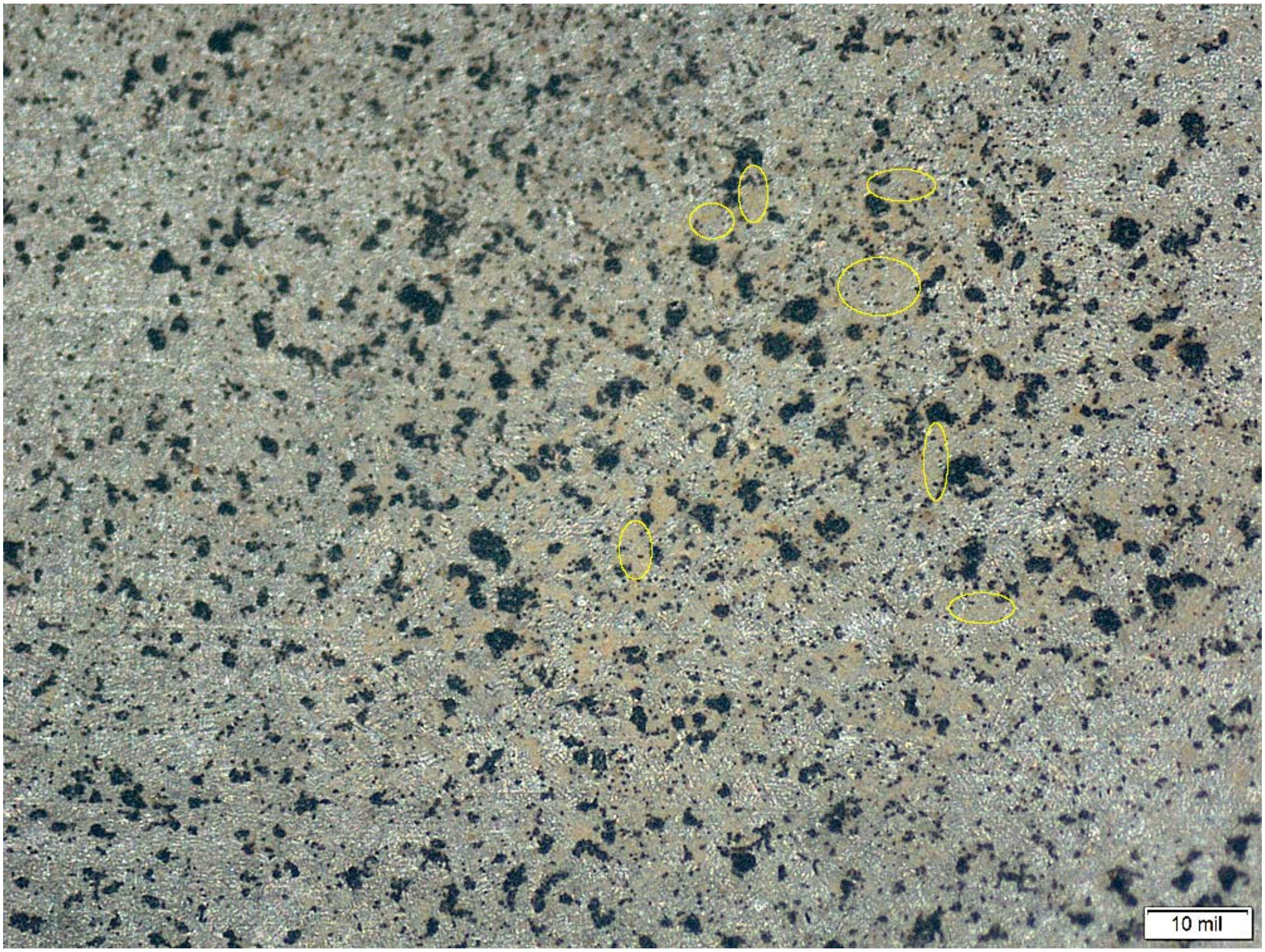

Figure 4: Stereo optical microscope image showing the center of the hail impact point damage on roof panel No.1; impact point 1A (Figure 1). The scale bar is in mils (0.001").

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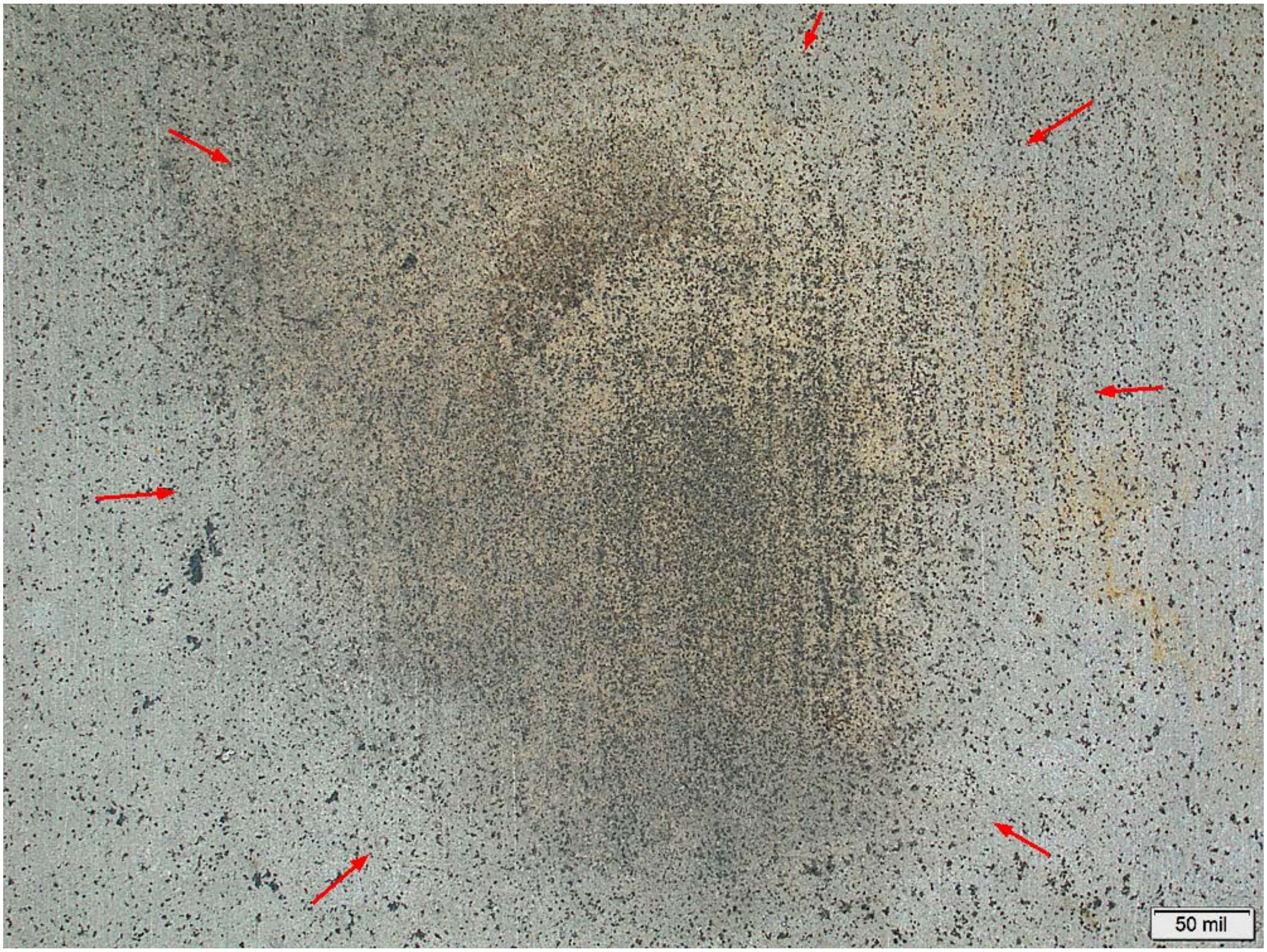

Figure 5: Stereo optical microscope image representative of the impact point of damage on roof panel No.1 impact point 1B (Figure 1). The scale bar is in mils (0.001").

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Figure 6: Stereo optical microscope image representative of the impact point of damage on roof panel No.1 impact point 1B (Figure 1). The scale bar is in mils (0.001").

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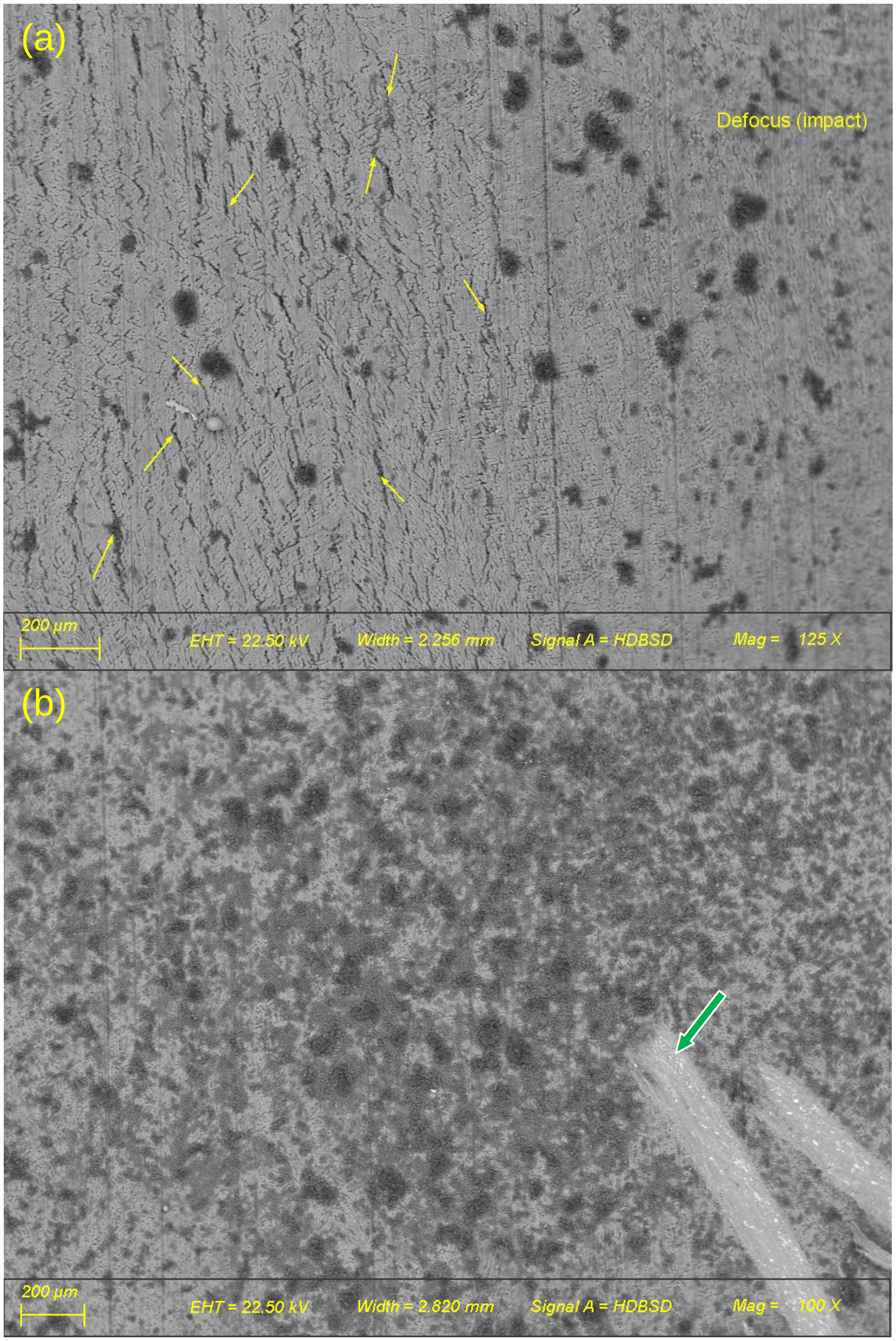

Figure 7: Backscattered electron (BSE) images representative of the impact point on roof panel No.1 at damage location 1A (Figure 1). The scale bars are in microns (μm). Scribe marks intentionally cut prior to the EM protocol are indicated (green filled arrow).

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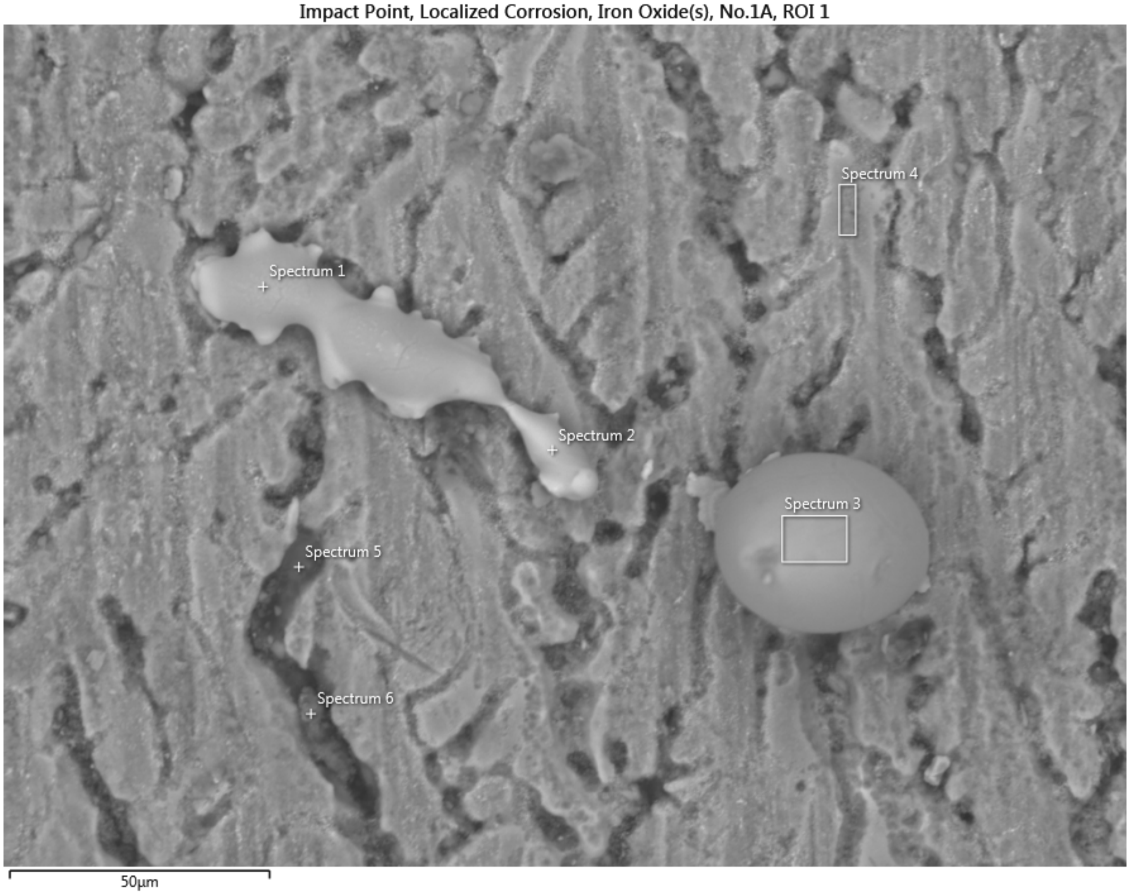
Impact Point, Localized Corrosion, Iron Oxide(s), No.1A, ROI 1



Label	Composition (wt.%)												
	O	Na	Mg	Al	Si	P	S	K	Ca	Ti	Cr	Mn	Fe	Zn
1	24.3			1.0								0.6	72.8	1.2
2	12.6			0.6								0.3	85.2	1.3
3	15.6			0.9	0.2							0.4	81.6	1.3
4	16.8	1.9		49.4	3.6					0.3	0.3		0.8	26.8
5	23.9	0.9	0.3	24.7	10.6	0.9	0.2	0.2	0.5	1.6	1.7		1.4	33.1
6	41.9	1.1	0.7	23.0	8.7	0.8	0.3	1.1	1.2	2.7	1.0		4.5	12.9

Figure 8: BSE image showing localized iron based corrosion products situated within the impact point of roof panel No.1 at damage location 1A, along with semi-quantitative EDS data (table) that were generated from the focused probe locations identified in the image.

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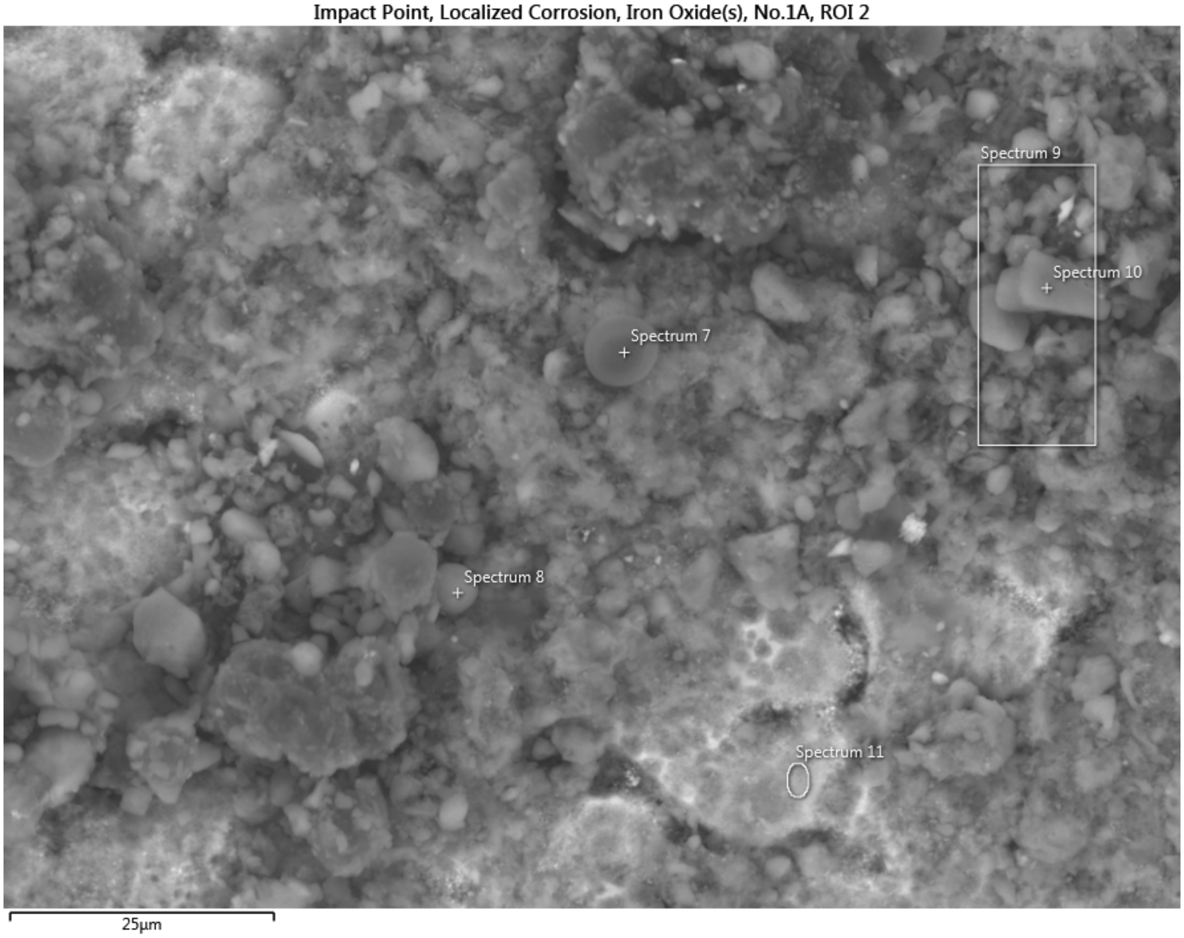
Impact Point, Localized Corrosion, Iron Oxide(s), No.1A, ROI 2



Label	Composition (wt.%)													
	O	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**K**	**Ca**	**Ti**	**Cr**	**Fe**	**Zn**	**Ba**
7	46.1	0.5	1.4	14.7	19.1	1.6	0.4	1.7	0.7	4.4	1.4	4.3	3.9	
8	27.0		0.9	20.5	38.0			3.3	1.7	1.6		4.3	2.7	
9	48.6	1.0	1.2	13.7	21.9	0.5		1.7	0.8	1.2	0.7	4.3	4.4	
10	40.9	3.2	0.5	13.9	30.9			1.6	4.6	0.2		1.7	2.1	0.4
11	7.3	2.7		58.5	1.5							0.4	29.6	

Figure 9: BSE image showing localized iron based corrosion products situated within the impact point of roof panel No.1 at damage location 1A, along with semi-quantitative EDS data (table) that were generated from the focused probe locations identified in the image.

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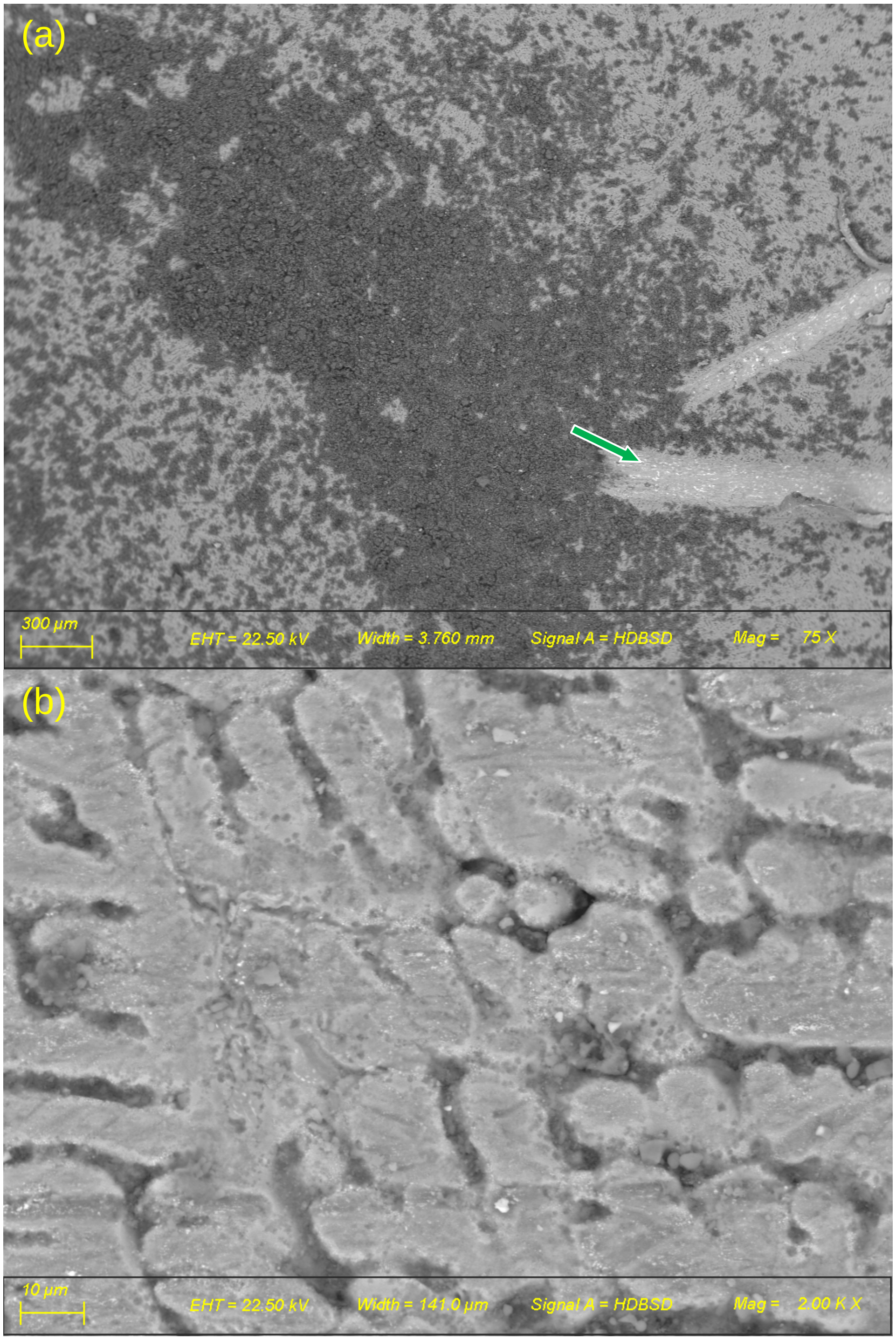

Figure 10: Backscattered electron (BSE) images representative of the impact point on roof panel No.1 at damage location 1B (Figure 1). The scale bars are in microns (μm). Scribe marks intentionally cut prior to the EM protocol are indicated (green filled arrow).

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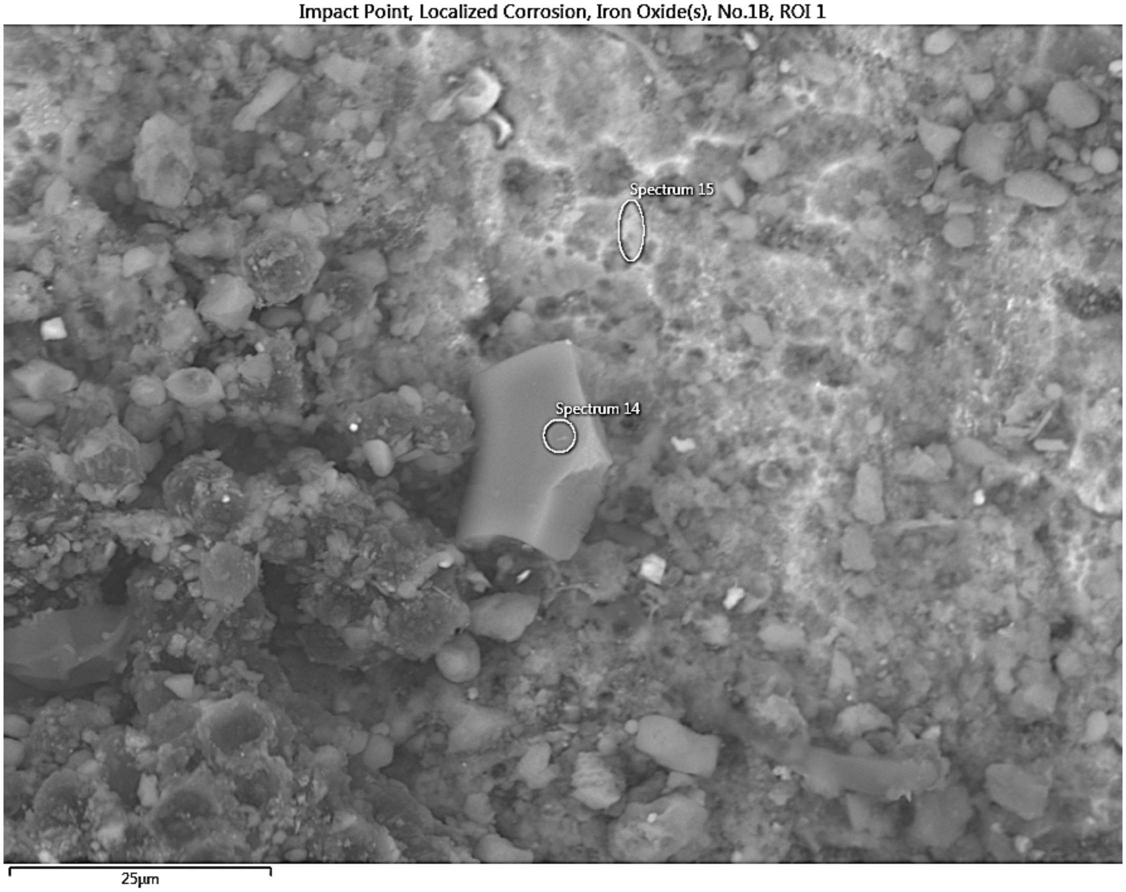
Impact Point, Localized Corrosion, Iron Oxide(s), No.1B, ROI 1



Label	Composition (wt.%)									
	O	Na	Mg	Al	Si	P	K	Ca	Cr	Fe	Zn
14	58.5		6.4	2.0	20.8		0.3	0.7	0.7	9.7	0.9
15	16.8	2.9		50.8	4.0	0.2				0.5	24.8

Figure 11: BSE image showing localized iron based corrosion products situated within the impact point of roof panel No.1 at damage location 1B, along with semi-quantitative EDS data (table) that were generated from the focused probe locations identified in the image.

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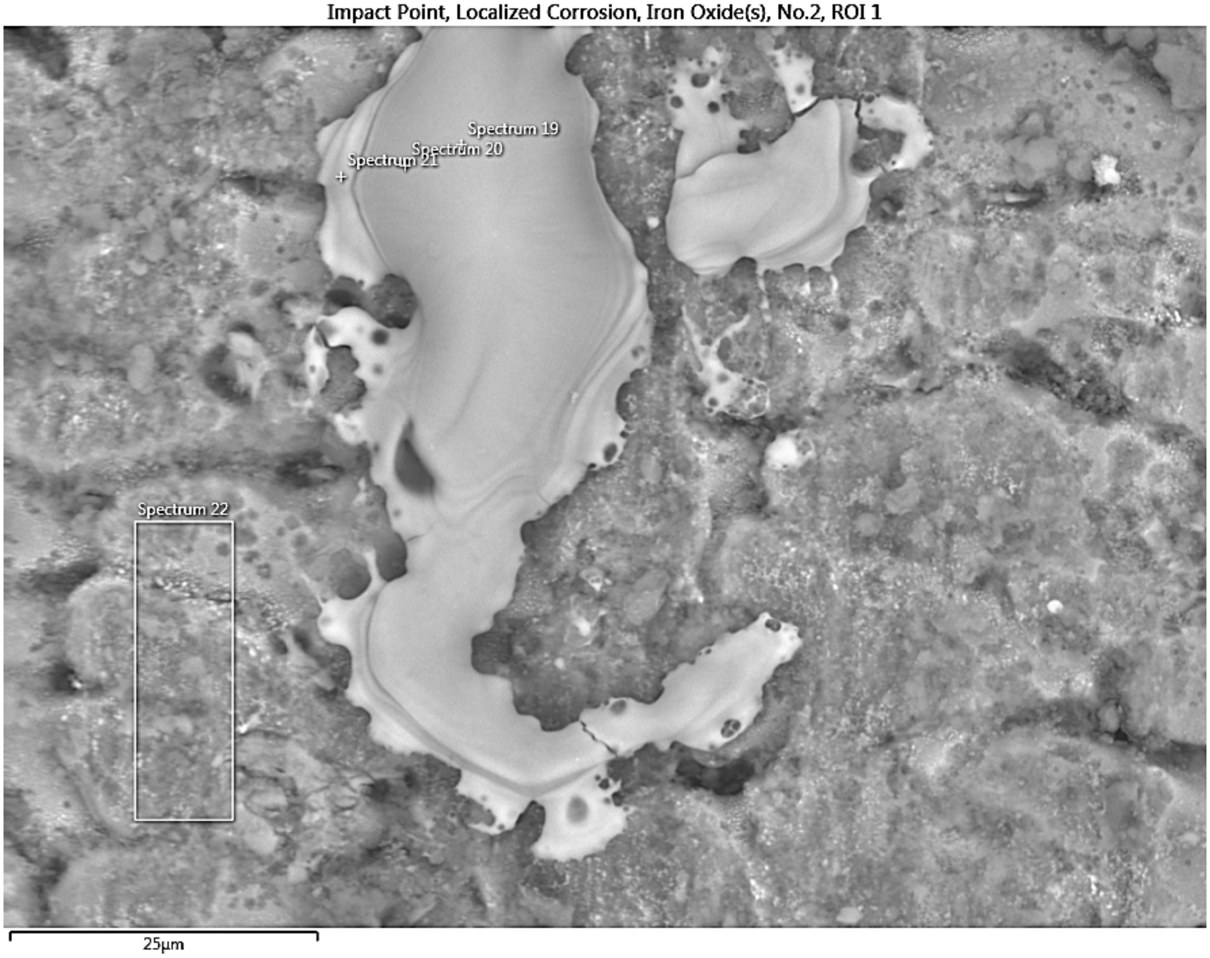
Impact Point, Localized Corrosion, Iron Oxide(s), No.2, ROI 1



Label	Composition (wt.%)							
	O	Na	Al	Si	Ti	Cr	Fe	Zn
19	27.0		0.7	0.2			70.6	1.6
20	32.4		1.7	0.4			63.6	1.9
21	31.0		2.3	0.8			63.6	2.5
22	16.2	2.0	52.9	2.8	0.3	0.7	1.2	24.0

Figure 12: BSE image showing localized iron based corrosion products situated within the impact point of roof panel No.2, along with semi-quantitative EDS data (table) that were generated from the focused probe locations identified in the image.

Jeffrey Molnar 1600 North Hickory Court, Broken Arrow, OK 74012. Mobile: 918.886.5141

Engagement: **Routinely performing electron and optical microscopy, primarily in the context of multiple and concurrently running failure investigations for a wide range of customers across multiple business sectors.**

Education: *Masters Of Engineering* - Michigan Technological University (04').
Bachelor Of Science - Metallurgical And Materials Engineering, Michigan Technological University (95').

Experience: *Failure Analyst, Metallurgical Consultant* (01/13' to Current), **Element Materials Technology.**

- Experienced with upstream and downstream pipeline, fracking equipment, and oil industry equipment failures; particularly events that have resulted in a release.
- Routinely perform corrosion based failure investigations for the Oil&Gas, Aerospace, and Automotive sectors.
- Proficient in performing failure investigations on advanced polymers and polymer-ceramic composites.
- Perform PCB Board characterization work, advanced electronic component failure investigations, and the reverse engineering of complex electronics.
- Perform on-site metallurgical examinations, particularly at oil refineries where catastrophic events have occurred with potential or established asset loss; often on the order of millions of dollars.
- Provide expert witness metallurgical/materials consulting in litigation cases.
- Interface directly with engineering managers, directors, executives, and business owners to identify, develop, and solidify engineering test protocols.
- Characterization of thin films via electron microscopy.
- Handle nearly all business and accounting aspects of each customer driven investigation.
- Manage routine maintenance, calibration, repair, and general day to day operations of the electron microscopy (EM) facility at Element Broken Arrow.
- Perform investigations requiring special topics in electron and optical microscopy.

Failure Analyst, Materials Engineer (10/08' to 10/12'). **Harris Corporation (ITT Night Vision).**

- Responsible for materials characterization and failure analysis work in support of manufacturing, product development, and research divisions.
- Manage small to large scale engineering projects requiring timely and accurate materials analysis, and provide recommendations to all levels of engineering management.
- Responsible for SEM, TEM, AFM, XRF, XRD, FTIR, OM, FIB, XPS, Spectral Ellipsometry, and Mechanical/Electrical Testing of Night Vision system components.
- Experience analyzing corrosion and mechanical failures of Titanium Alloys, Aluminum Alloys, Nickel Base Alloys, and composite structures.
- Responsible for product quality testing (PQT).
- Publish in depth technical reports to senior process engineers and engineering management.

Senior Microscopist (03/04' to 10/08'). **Thermo Fisher Scientific (Lancaster Laboratories).**

- Responsible for the analysis and characterization of organic and inorganic end products, competitor products, and new products developed by the clients operations.
- Perform SEM, ESEM, OM, Ultramicrotomy, and Confocal Microscopy to characterize metallics, polymers, composite materials, and naturally occurring materials such as wood, and plants.
- Interface with engineering staff to assess project goals and provide materials characterization work in support of product development and process changes.
- Developed a novel polymer/polymer fiber using a single stage process versus the industry wide and typical multi-stage processes (global publication).
- Generate detailed technical reports to senior management and staff engineers.

Awards: *ITT Exelis SILVER Ring Of Quality Award* – Identified, characterized, tested, and implemented a new material system to Night Vision Goggles; this achievement was documented at ~2.5M per year cost savings to manufacturing and operations.

Publications: Mishra K., Yu H., Molnar J., Baliga V., "Design Of A Polymer Blend For One-Step Porous Fiber Fabrication", Designed Monomers And Polymers, Volume 12, Number 3, pp. 273-278.

Certifications: VBLSS Green Belt.

Activities: Ice Hockey, Woodworking, Tennis, Golf.